The Kinematics of Shoulder Impingement: Glenohumeral Joint Positions and the Effects on Rotator Cuff Tendon Clearance

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The infraspinatus, supraspinatus, and subscapularis were considered when looking at impingement in ten subject anatomical models. The infraspinatus and supraspinatus were found to be the sources of impingement for symptomatic subjects in two representative positions: reaching up behind the back and reaching into the back pocket. The minimum distances were found to be smaller and area of contact between the tissues and the acromion and coracoacromial ligament were found to be larger in symptomatic subjects. These results support that the impingement of these structures may cause symptoms in the subjects.

Introduction

Shoulder mechanical impingement is the compression and mechanical abrasion of the rotator cuff structures as they pass beneath the coracoacromial arch and is fairly common among a variety of occupations and recreational activities.[5,7] Occupational and recreational exposure to overhead arm use and wheelchair use leads to a prevalence of shoulder pain in these populations of greater than 50%.[1,3,6] Shoulder pain affects use of the arm and can become a debilitating condition that greatly affects quality of life. For occupations associated with overhead arm use, pain and loss of function can significantly impair a worker's ability to perform certain tasks comfortably or at all. Detrimental functional consequences are seen by wheelchair users who experience shoulder pain and impairment as their shoulders are imperative to mobility.[1] Rotator cuff pathology is the most common tendon pathology and leads to rotator cuff tears that require surgical intervention.[7] Currently, many patients do not improve significantly through therapy and will continue to have recurring symptoms. Furthermore, a majority of patients only improve 50-60% toward the level of function of age matched healthy subjects.[4] Several theoretical mechanisms exist to describe cuff pathology, but it is unclear which kinematic abnormalities are most harmful and to what degree kinematic change must occur to increase impingement risk. Rotator cuff tendon clearance is the space available for the cuff and long head of the biceps tendons to pass without contact with an impinging structure while moving the arm. Without this clearance, compressive and frictional forces and soft tissue impingement can have painful consequences. Knowledge of the kinematic mechanisms of impingement and rotator cuff disease and quantitatively understanding rotator cuff tendon clearance is imperative to diagnostic and rehabilitation approaches. This study aims to identify impingement in two positions: reaching up behind the back and reaching into the back pocket to find both the minimum distances and area of contact between the tissues and impinging structures. There is a higher expected risk of subacromial impingement when reaching up behind the back.

Method

3D shoulder anatomical models were previously created and include the scapula, humeral head and proximal shaft, distal clavicle, coracoacromial ligament, rotator cuff tendon insertions, immediately proximal rotator cuff musculature, and long head biceps tendon. These models were constructed using soft tissue data from high resolution MR imaging. A sphere was fit to the humeral head using an optimization algorithm in MATLAB. Points placed on the perimeter of the distal humerus and glenoid rim were used in an optimization algorithm to find the center of the distal humerus and the center and plane of the glenoid. To create the coordinate system, the posterior lateral acromion, root spine of the scapula, inferior angle, superior glenoid, bicipital groove, humeral head center and radius, glenoid center and plane, and distal humeral center were identified as points on the 3D model. A MATLAB algorithm used these points and the structures of the acromion, supraspinatus, infraspinatus, subscapularis, coracoacromial ligament, and glenoid to create a coordinate system. The humerus, infraspinatus, supraspinatus, and subscapularis were rotated to the identified positions using this system. The positions were determined from analyzing twenty five human subjects in different positions. The first position was not measured from human subjects and was a forced position on the anatomical models. The positions are as follows: the neutral position with an adjustment for retroversion (1), reaching into the back pocket (2), and reaching up behind the back (3). The following angles were measured: the glenohumeral elevation angle, the glenohumeral plane, and glenohumeral rotation. For a right handed shoulder, the glenohumeral elevation angle is defined as the angle of elevation of the humerus where a negative elevation is abduction. The glenohumeral plane is defined as the angle of the humerus in front of or behind the scapular plane where the angle behind the back is negative. Glenohumeral rotation is the long axis rotation of the humerus and internal rotation is positive. Table 1 contains the values for each angle that were used to describe the shoulder in the three different positions. To get the humerus in the initial position, all models had a retroversion of 30°.[2] This position is not necessarily a neutral position of the shoulder but is a standard starting point for all models so that the angles for the positions are uniform. All additional rotation is added to the initial 30° retroversion.

Table 1. Values for the three angles that describe the shoulder in three positions.

Position	Elevation	Plane	Rotation
1: Neutral with Adjustment for Retroversion	0	0	30
2: Reach Into the Pocket	-3.02	-37.4	30.3
3: Reach Up Behind the Back	-6.18	-33.7	49.0

After the tissues were rotated, they were imported to the 3D model to visualize the rotations. These rotated positions were used in another MATLAB algorithm to find distance and areas between bones and the tissues. The minimum distances between the subscapularis, infraspinatus, supraspinatus, and humerus and the coracoacromial ligament and acromion were determined for each subject in the position of retroversion, reaching into the back pocket, and reaching up behind the back. In addition to the minimum distances, the area of tissue at a distance between zero and one millimeter was found. A distance of this magnitude is defined as contact between the tissue and bone and a potential source of pain. The minimum distances and areas of contact were compared across models and between symptomatic and asymptomatic subjects. The tissues with potential risk of impingement in these positions are the infraspinatus and supraspinatus.

Results

Table 1. Average minimum distances between the supraspinatus and acromion and coracoacromial ligament.

Position	Subjects	Mean(mm)	SD(mm)	Min(mm)	Max(mm)	Range(mm)
1	All	0.664	1.77	0.0702	5.71	5.64
	Symptomatic	0.0928	0.0152	0.0702	0.103	0.0328
	Asymptomatic	1.04	2.28	0.0889	5.71	5.62
2	All	0.592	1.43	0.0697	4.66	4.59
	Symptomatic	0.131	0.0551	0.0755	0.185	0.109
	Asymptomatic	0.899	2.28	0.0889	5.71	5.62
3	All	0.627	1.22	0.0541	3.95	3.89
	Symptomatic	0.145	0.114	0.0541	0.311	0.256
	Asymptomatic	0.948	1.54	0.0776	3.95	3.87

Table 2. Average minimum distances between the infraspinatus and acromion and coracoacromial ligament.

Position	Subjects	Mean(mm)	SD(mm)	Min(mm)	Max(mm)	Range(mm)
1	All	2.84	1.77	0.419	6.21	5.79
	Symptomatic	1.82	0.738	1.10	2.78	1.68
	Asymptomatic	3.52	1.98	0.419	6.21	5.79
2	All	1.01	1.29	0.0360	3.38	3.35
	Symptomatic	0.846	1.13	0.0360	2.45	2.42
	Asymptomatic	1.48	1.50	0.0634	3.38	3.32
3	All	1.10	1.24	0.0354	3.31	3.28
	Symptomatic	0.458	0.587	0.0354	1.33	1.29
	Asymptomatic	1.52	1.47	0.0634	3.38	3.32

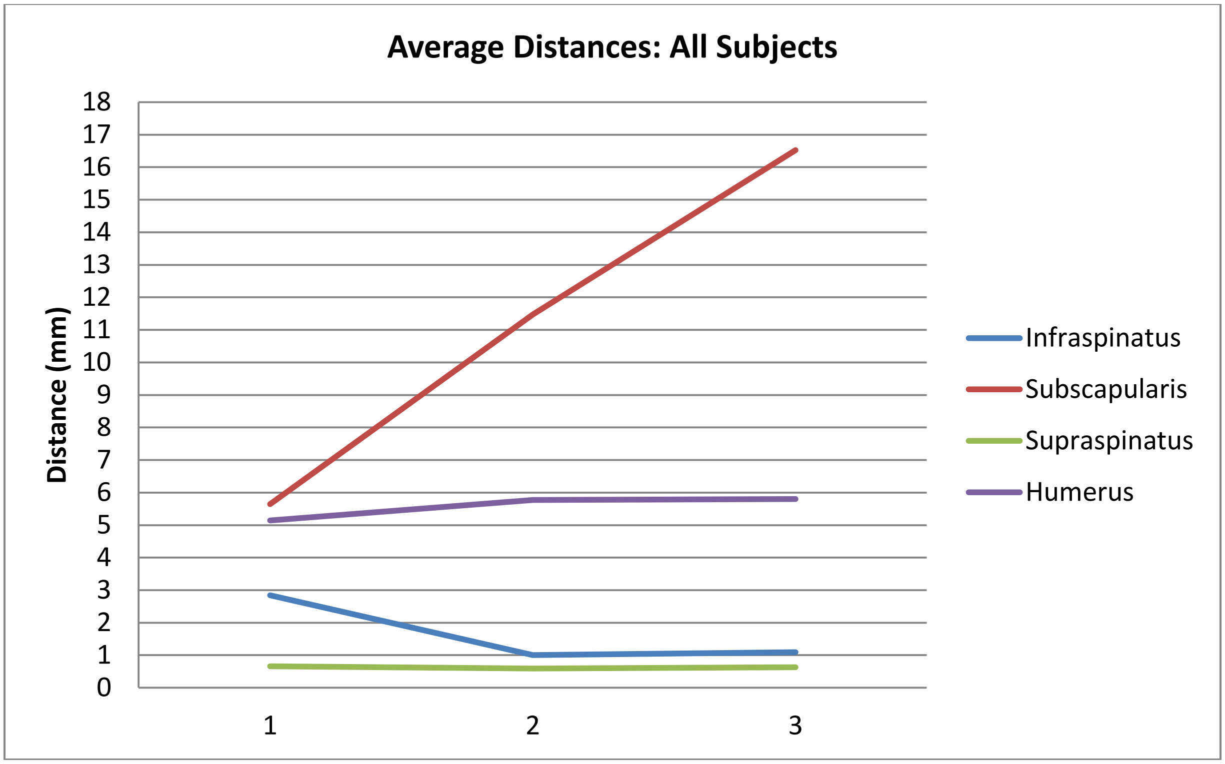

Figure 1. The minimum mean distances between the tissue and the acromion and coracoacromial ligament across all models in the three specified positions. This graph displays data for the humerus and subscapularis, which are not a potential source of impingement.

Table 3. Average area of contact between the supraspinatus and acromion and coracoacromial ligament.

Position	Subjects	Mean(mm^2)	SD(mm^2)	Min(mm^2)	Max(mm^2)	Range(mm^2)
1	All	158	149	104	97.2	99.6
	Symptomatic	174	96.9	45.2	274	229
	Asymptomatic	147	101	0	264	264
2	All	88.8	100	104	91.8	80.4
	Symptomatic	106	55.6	57.7	183	125
	Asymptomatic	77.0	67.7	0	177	177
3	All	67.1	89.5	108	83.4	84.0
	Symptomatic	101	68.6	19.7	186	167
	Asymptomatic	44.8	46.7	0	125	125

Table 4. Average area of contact between the infraspinatus and acromion and coracoacromial ligament.

Position	Subjects	Mean(mm^2)	SD(mm^2)	Min(mm^2)	Max(mm^2)	Range(mm^2)
1	All	5.13	16.2	0	51.3	51.3429
	Symptomatic	0	0	0	0	0
	Asymptomatic	8.56	21.0	0	51.3	51.3
2	All	69.2	78.5	0	219	219
	Symptomatic	82.4	94.7	4.15	219	215
	Asymptomatic	60.4	73.9	0	168	168
3	All	59.6	85.8	0	255	255
	Symptomatic	84.6	116	0	255	255
	Asymptomatic	41.0	65.9	0	170	170

Discussion

The neutral position adjusted for retroversion is not a natural position. It is a forced position of the anatomical model to standardize all future rotations. The distances in this position do not reflect when the subject is in a neutral resting position, and therefore, do not reveal any information about impingement when subjects are at rest.

The second position, reaching into the pocket, has significant consequences for impingement of the infraspinatus and supraspinatus. The mean minimum distance for the infraspinatus in this position is 0.846 mm in symptomatic subjects and 1.48 mm in asymptomatic subjects. The mean area of contact for symptomatic subjects is 82.4 mm^2 and 60.4 mm^2 for asymptomatic subjects. The mean minimum distance for the supraspinatus in this position is 0.131 mm and 0.900 mm for symptomatic subjects and asymptomatic subjects respectively. The mean area of contact for symptomatic subjects is 106 mm^2 and 77.0 mm^2 for asymptomatic subjects. In this position, the infraspinatus and supraspinatus have significant areas of contact in the symptomatic subjects. A larger area of contact will likely be a cause of pain and limited range of motion.

Reaching up behind the back is the third position. Impingement is also evident here. The mean minimum distances for the infraspinatus in symptomatic and asymptomatic subjects, respectively, are 0.458 mm and 1.52 mm. The mean area of contact for the infraspinatus in symptomatic subjects is 84.6 mm^2 and 41.0 mm^2 for asymptomatic subjects. The mean minimum distances for the supraspinatus in symptomatic subjects and asymptomatic subjects, respectively, are 0.145 mm and 0.948 mm. Symptomatic subjects had a mean area of contact of 101 mm^2 while asymptomatic subjects had a mean area of contact of 44.8 mm^2. The larger difference in area of contact between symptomatic and asymptomatic subjects in this position indicates that reaching up behind the back is a greater risk for impingement than reaching into the back pocket.

Limitations of this study include using forced positions in the anatomical models. The angles used were based off of an average of 25 subjects in those positions and do not reflect the angles for individual subjects in each position. The angles vary slightly for each person which induces a small error in the measured distances between structures for each person. Only ten anatomical models were studied, and if more models were analyzed, the results could provide more definite outcomes on impingement in these positions. There are small variations in the structures when making anatomical models from MR data which creates additional error. Having more subjects could reduce the effect of this error in the overall results.

Further study can be done by including more subjects and analyzing additional positions. By analyzing additional positions, the mechanisms of impingement can be better understood and used to alleviate pain and increase function in patients with shoulder pain.

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